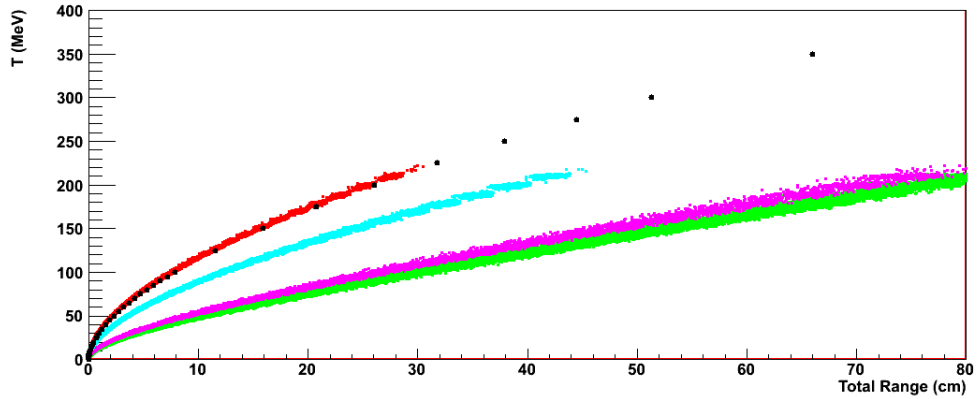
Calorimetric reconstruction (& PID) of ArgoNeuT events in LArSoft

Kinetic Energy
vs. total range
(track length)



GEANT4 MC predictions

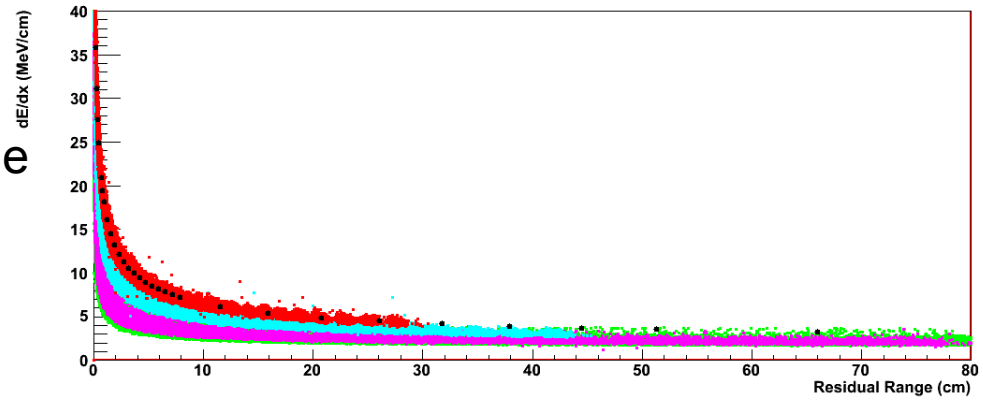
p

K

π

μ

dE/dx
vs. residual range



- NIST predictions (p)

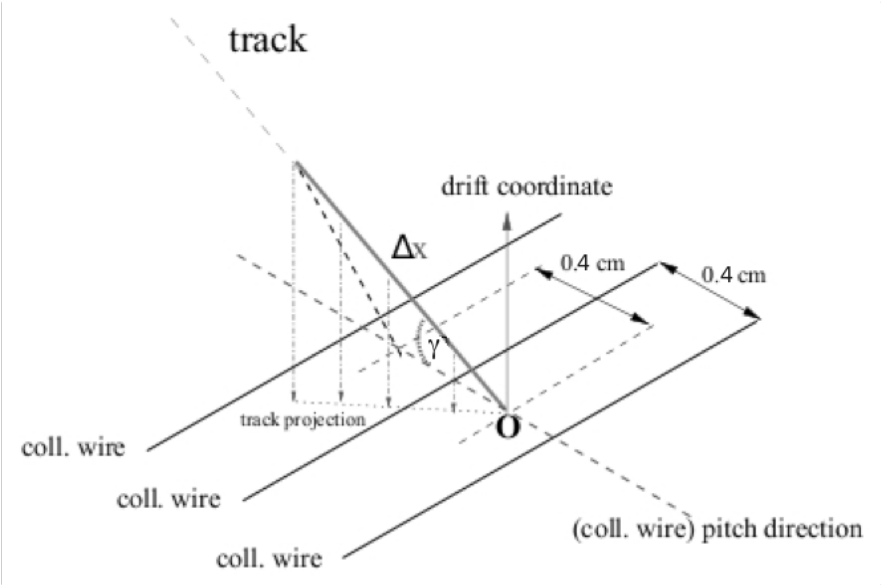
- Real data studies
- MC data studies

} ArgoNeuT

Calorimetric reconstruction (I)

- After the 3D geometric reconstruction, determination of the energy release in LAr is performed by the further steps:
  1. account for the charge loss due to electro-negative impurities
  2. charge to energy conversion with correction for the quenching effect

❑ The hit amplitude dQ (in units of ADC counts) is normalized for the track pitch length (i.e. the effective length of the portion of track exposed to a single wire, depending on the orientation of the track with respect to the direction of the wires in the plane) dQ/dx [ADC/cm]



Calorimetric reconstruction (II)

- An electronic calibration factor

f_{Cal}=7.54 ADC/fC (for ArgoNeuT)

is applied to convert from ADC count to charge expressed in number of electrons dQ/dx [e/cm]

1. To account for the charge loss along the drift due to electro-negative impurities the charge dQ/dx [e/cm] is multiplied by $e^{(t-t0)/\tau}$,where $(t-t_0)$ is the hit drift time and τ is the measured electron lifetime (measured run by run, ~750 μs for ArgoNeuT @ NuMI – ν mode).

2. The full calorimetric reconstruction is performed accounting for the quenching effect on the ionization charge, using Birks model, to convert dQ/dx [e/cm] to energy released per unit length dE/dx [MeV/cm]. From the parameterization of the recombination formula in ICARUS, NIM 523 (2004), 275:

$$\frac{dE}{dx} = \frac{\frac{dQ}{dx}}{\frac{A}{W_{ion}} - \frac{K}{E_{Field}}\frac{1}{\rho}\frac{dQ}{dx}}$$

depends on the ionization density (dQ/dx)

$A_{3t} = 0.800 \pm 0.003,$

$k_{3t} = 0.0486 \pm 0.0006 \text{ kV/cm}\,\frac{\text{g/cm}^2}{\text{MeV}}$

Calorimetry package in LArSoft (T962/Calorimetry)

For each reconstructed track:

```
Run = 621 Event = 8190 #T962 Tracks = 2 #MINOS Tracks = 3
T962 Track ID    0 #SpacePoints =    56 #Clusters =   2 Theta =  0.272 Phi =  2.233
StartCosines : ( -0.165  0.212  0.963 )  EndCosines : ( -0.165  0.212  0.963 )

T962 Track ID    1 #SpacePoints =     7 #Clusters =   2 Theta =  0.931 Phi = -0.389
StartCosines : (  0.742 -0.304  0.597 )  EndCosines : (  0.742 -0.304  0.597 )

1 Matchable T962 tracks.
 Run 621 Event 8190 Match! T962 Track #0 and MINOS Track #1.00
 |-* ArgoNeuT track #0, escaping
 |-*                    Track Length=33.15 cm
   |-* Collection View Calorimetric Reco
     |-* Hits=69
     |-* <dE/dx>=2.03 MeV/cm
     |-* Kinetic Energy deposited in LAr=59.66 MeV
 |-* ArgoNeuT track #1, contained
 |-*                    Track Length=6.54 cm
   |-* Collection View Calorimetric Reco
     |-* Hits=7
     |-* <dE/dx>=7.48 MeV/cm
     |-* Kinetic Energy deposited in LAr=57.37 MeV
     |-* <dE/dx>_5cm 8.26 MeV/cm
```

Passing, entering, contained, escaping

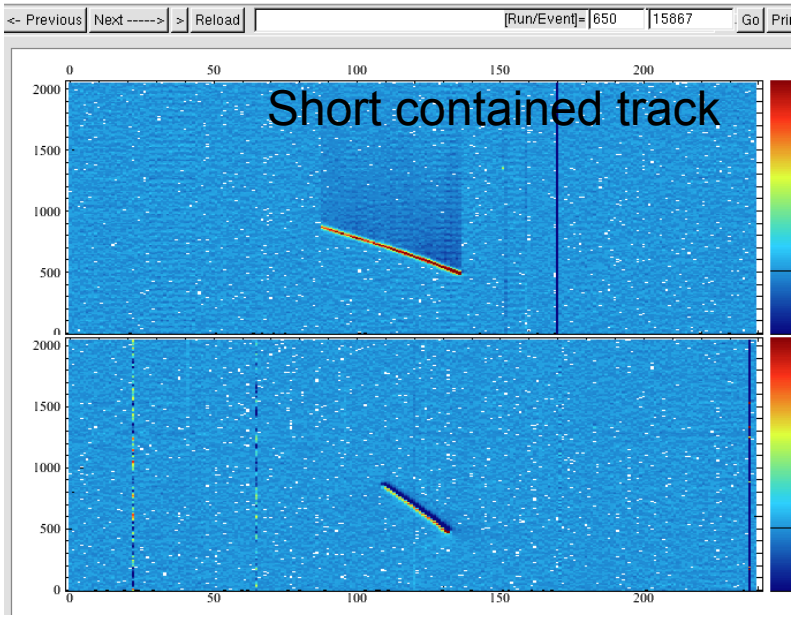
<dE/dx>, kinetic En. deposited in LAr

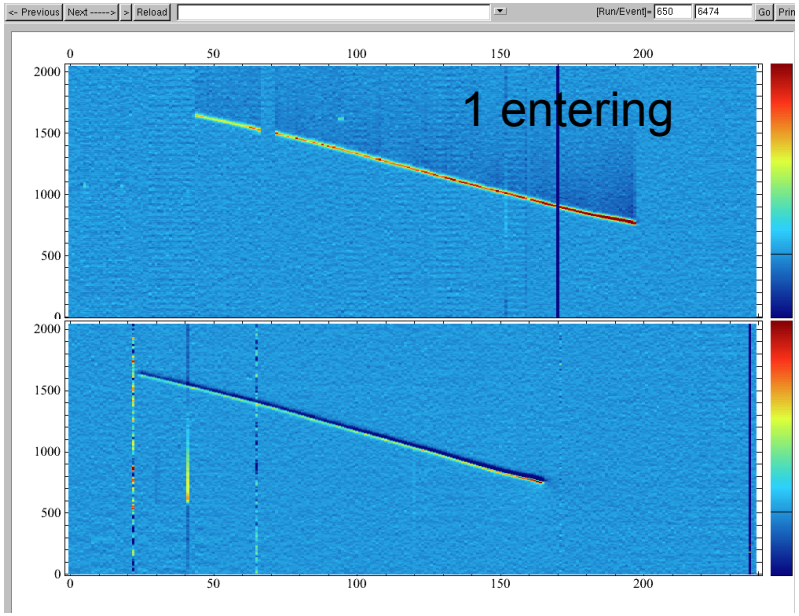
Histos of dE/dx, dE/dx vs. residual range, kinetic energy,
Kinetic energy vs. total range (track length)
for all reconstructed tracks

(Some new features recently added)

REAL DATA: PID and reconstruction of protons (evts with single tracks)

9 events like:

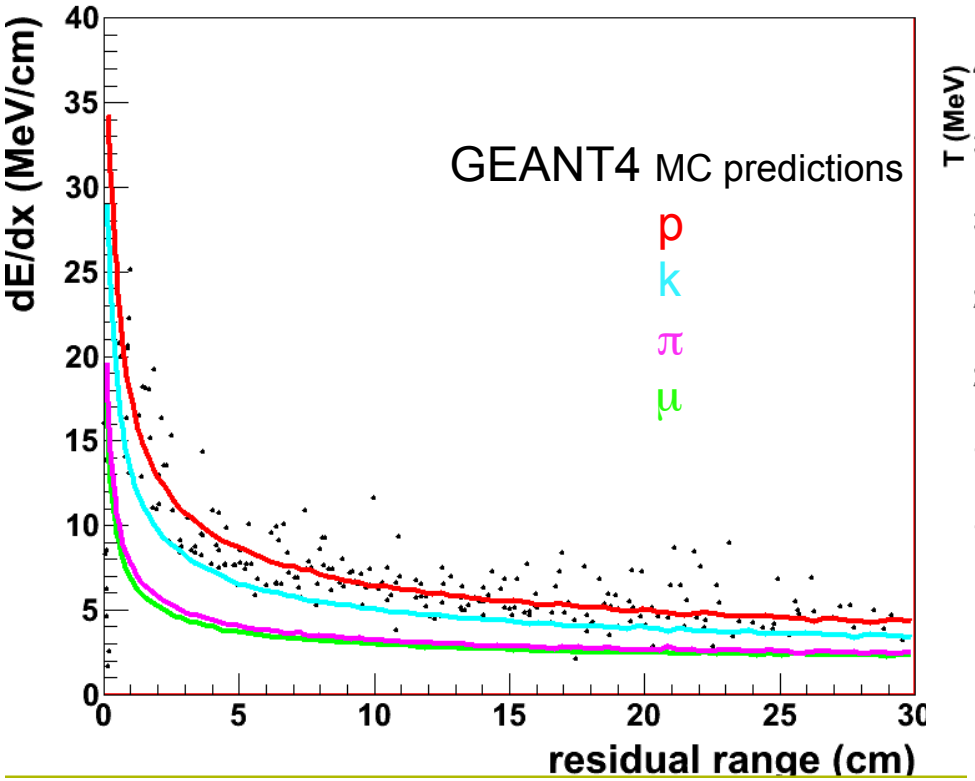




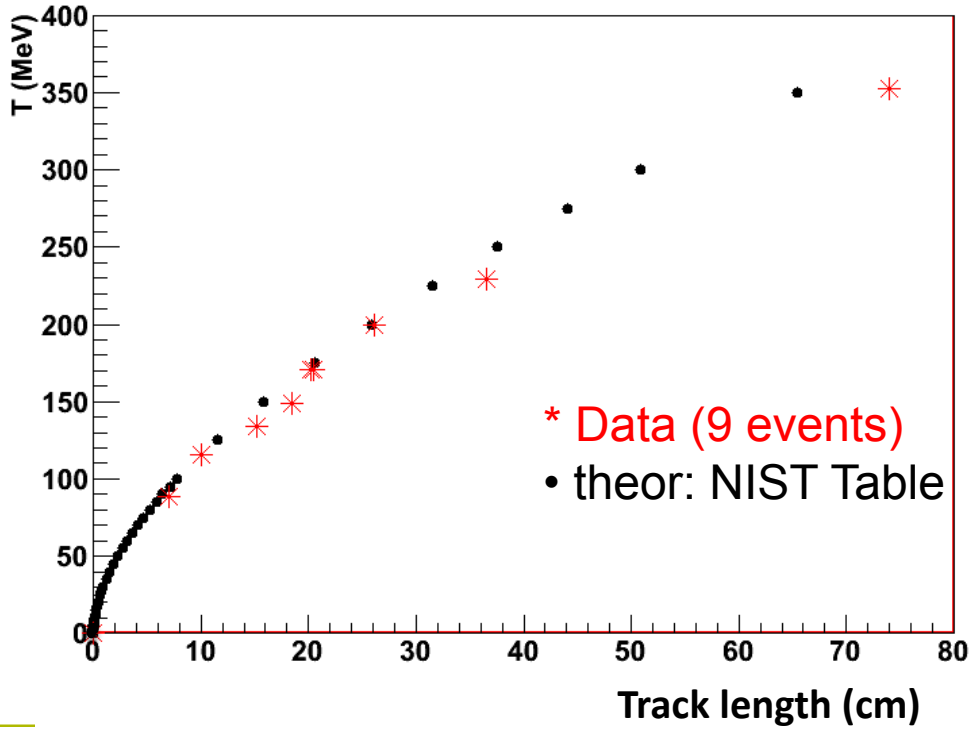
We are plenty of this kind of events!!
The origin of these events
need to be fully understood
(neutrons, NC events …?)

REAL DATA: Protons - comparison with expectations

Measurement of dE/dx along the track, of the Kinetic energy deposited and of the track length



NIST predictions (**Stopping-Power and Range Tables)**



Calorimetric reconstruction of protons:
very good agreement with expectations!

ArgoNeuT

MC DATA:

- Used to prove the reliability of the calorimetric reconstruction

- Simulation of events in LArSoft:
  a) in LArVoxelReadout::DriftIonizationElectrons the energy deposited (from GEANT4) in a Voxel is converted in # of electrons taking accounting for:
     1. charge loss due to electro-negative impurities (lifetimecorrection)
     2. charge to energy conversion with correction for the quenching effect (recomb)

nElectrons = lifetimecorrection * energy * recomb * nElectrons_const

lifetime τ=750 μs and Elec. Field=500 V/cm

$$A_{3t} = 0.800 \pm 0.003,$$

$$k_{3t} = 0.0486 \pm 0.0006 \text{ kV/cm} \frac{\text{g/cm}^2}{\text{MeV}}$$

$$\left(k_Q = \frac{k}{\mathscr{E}}\right). \qquad (9)$$

Corresponding to $k_Q = 0.097 \pm 0.001$ (g/cm^2)/MeV at 0.5 kV/cm, in good agreement with the value in Ref. [3].

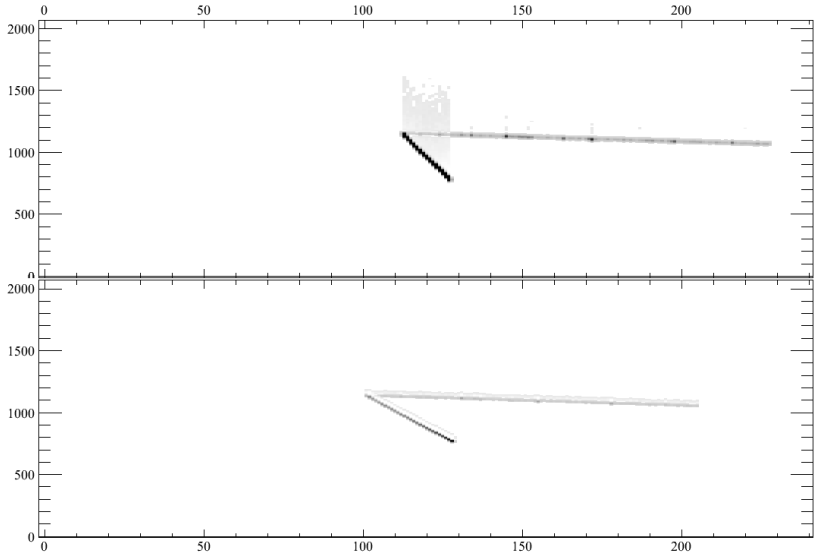
recomb is calculated from the parameterization in ICARUS, NIM 523 (2004), 2

$$Q = A \frac{Q_0}{1 + k/\mathscr{E}\, \mathrm{d}E/\mathrm{d}x}$$

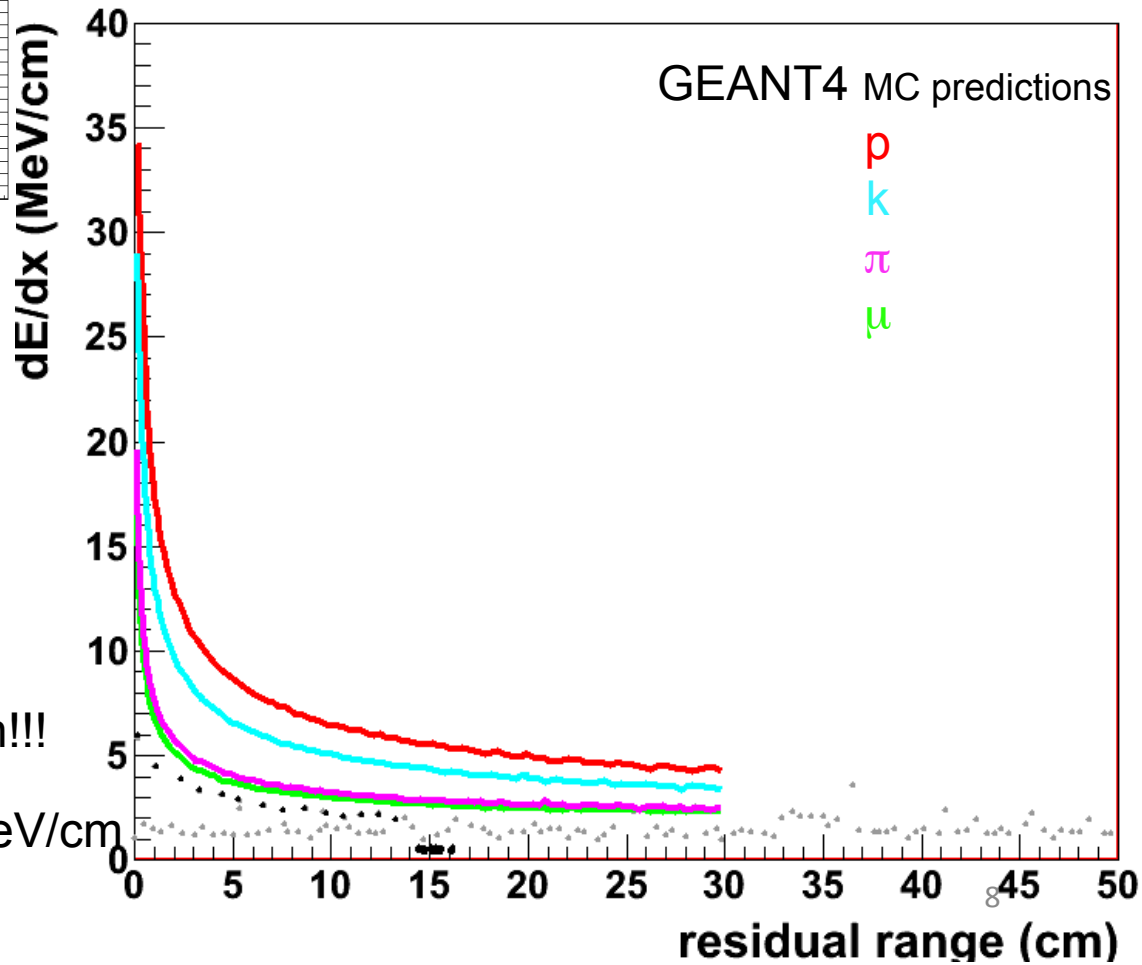
recomb = fRecombA/(1. + (energy/dx)*fRecombk);

[MeV/cm]*[g/cm^2/MeV] !

0) **CCQE (GENIE)** events (generated by Kinga)



Raw data



After reconstruction:

black points: rec. MC p

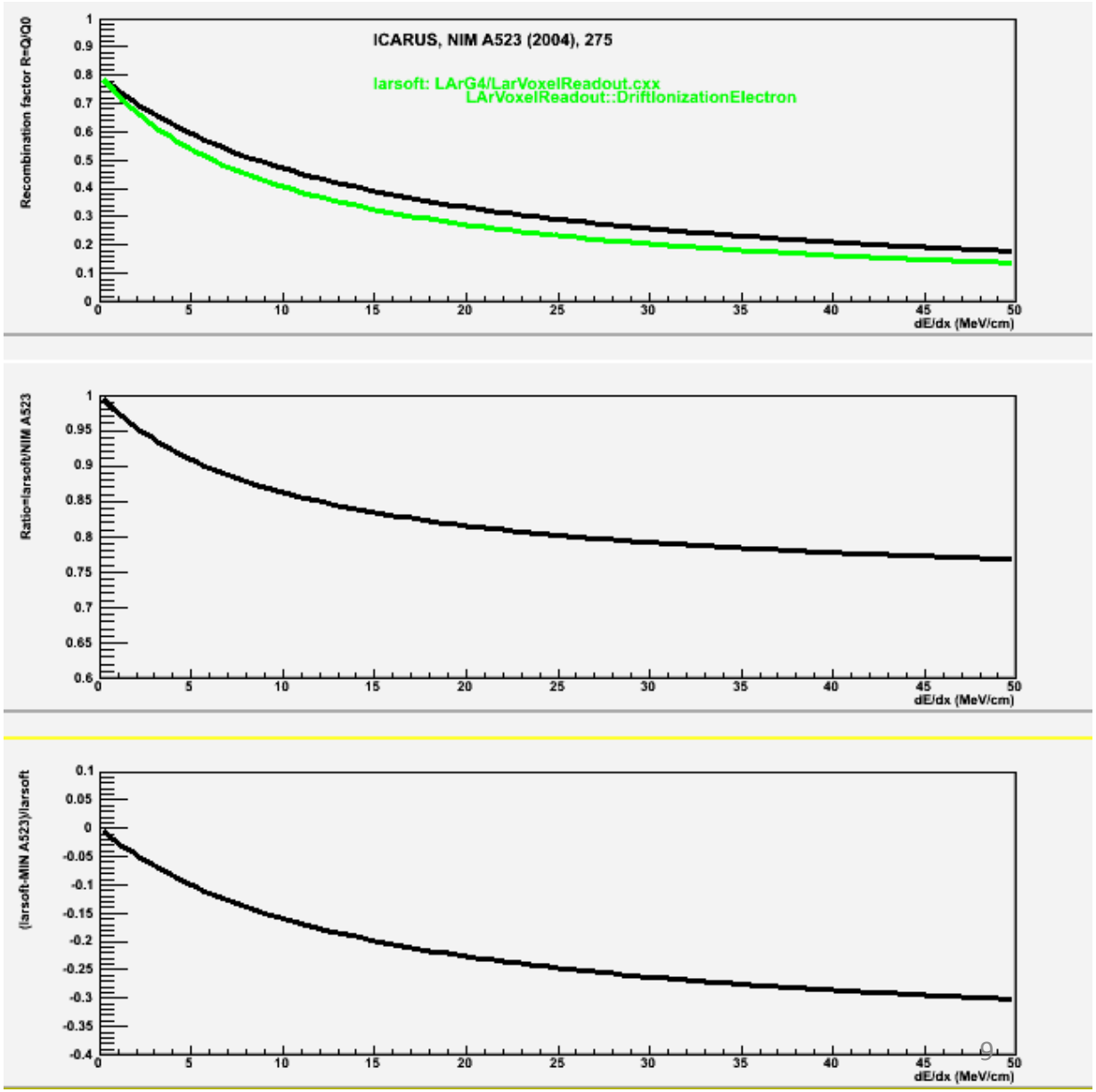
grey points: rec. MC μ

Very far from GEANT prediction!!!

1.5 MeV/cm

-The density of the Argon **was not taken into account** in the recombination formula.

- This has an important **(non-linear)** effect on the signal amplitudes of MC events.



1) **GeV Muons** - tracks parallel to the wire plane

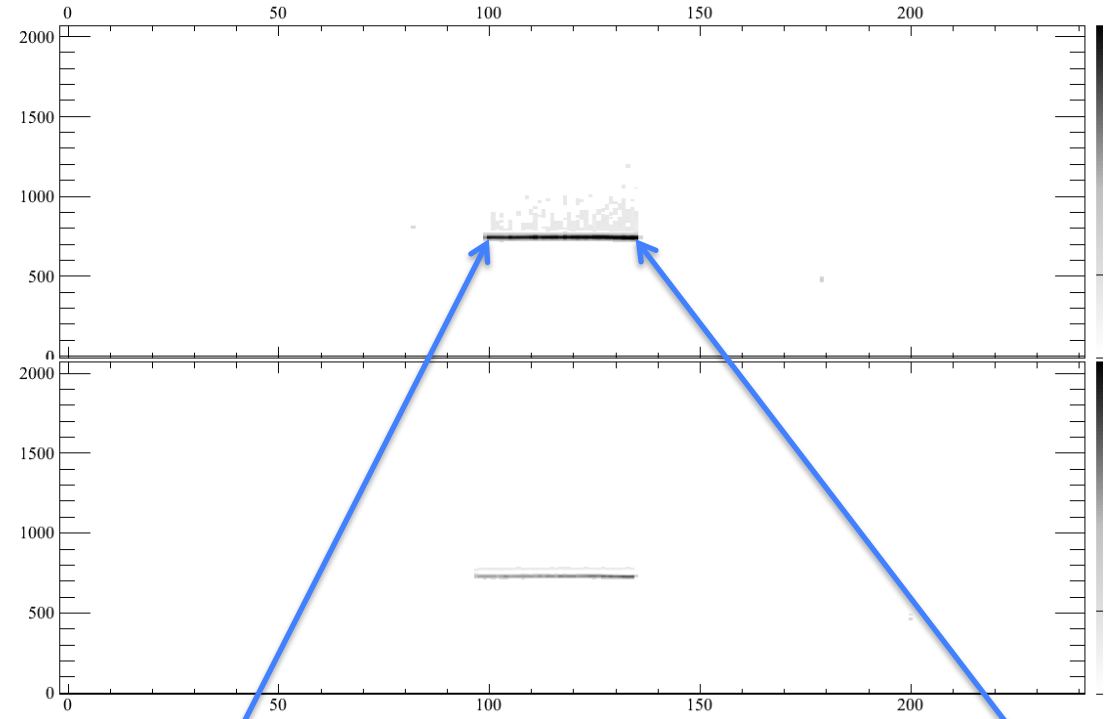
raw **MC** data Coll. Plane ~ 22 ADC; <dQ/dx>=54 ADC/cm,

from calorim. Rec. <dE/dx>=1.5 MeV/cm !!

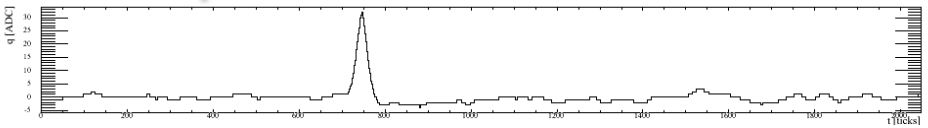
[*to be compared with: raw Real data Coll. Plane ~ 26 ADC; <dQ/dx>=63 ADC/cm;*

<dE/dx>=2.2 MeV/cm]

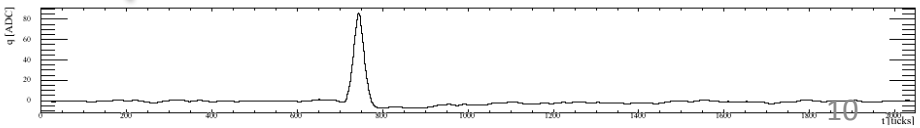
2) **185 MeV protons** (MC - generated by Kinga) – raw data:



I Coll. wire ~ 30 ADC



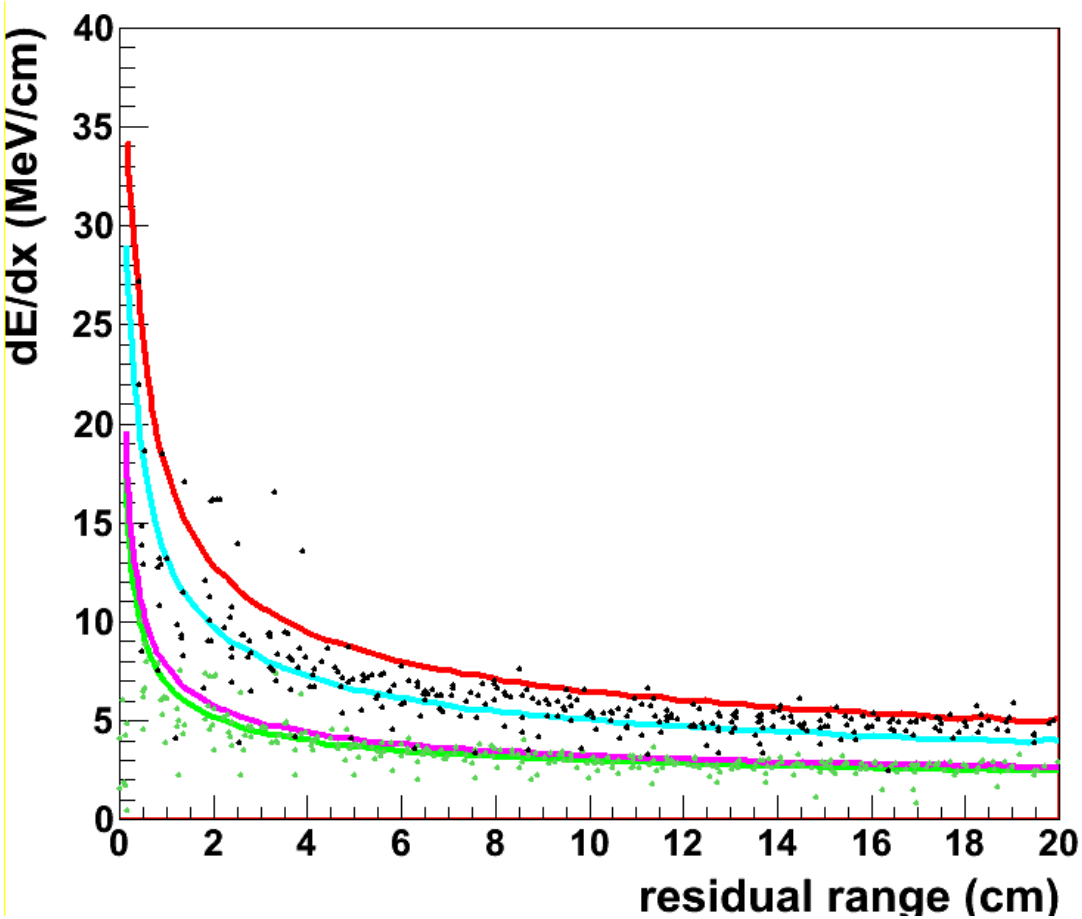
Last Coll. wire ~ 84 ADC



185 MeV protons (MC - generated by Kinga) after reconstruction:

green points: MC p reconstructed with the electronic calibration factor f_{cal}=12 ADC/fC (as reported in larsoft DetectorProperties in Utilities)

black points: MC p reconstructed with f_{cal}=7.54 ADC/fC (as for real data)



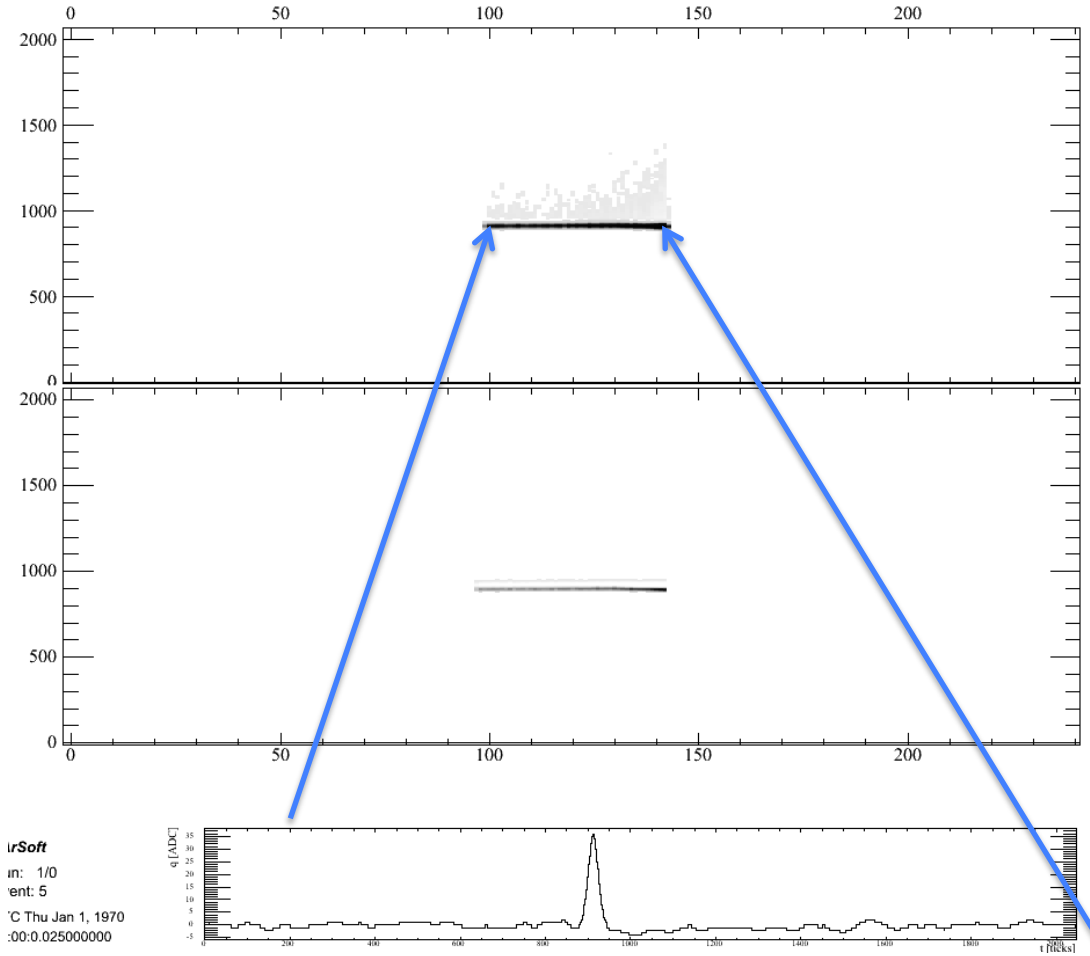
Change to the recombination factor in LArSoft, to include the LAr density (Jan. 13 2012)

fRecombk = lgp->Recombk()/**density**;

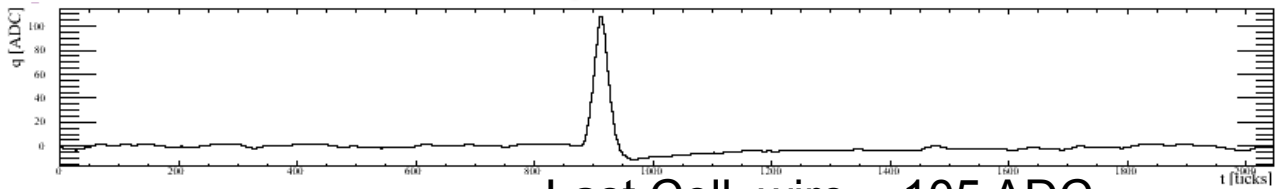
1) **GeV Muons** - tracks parallel to the wire plane **– after change**
raw **MC** data Coll. Plane ~ 26 ADC; <dQ/dx>=63 ADC/cm,
from calorim. Rec. <dE/dx>=2.2 MeV/cm in agreement with real data

[*to be compared with: raw Real data Coll. Plane ~ 26 ADC; <dQ/dx>=63 ADC/cm; <dE/dx>=2.2 MeV/cm]*

2) **185 MeV protons** (MC - generated by Kinga) – raw data – **after change**

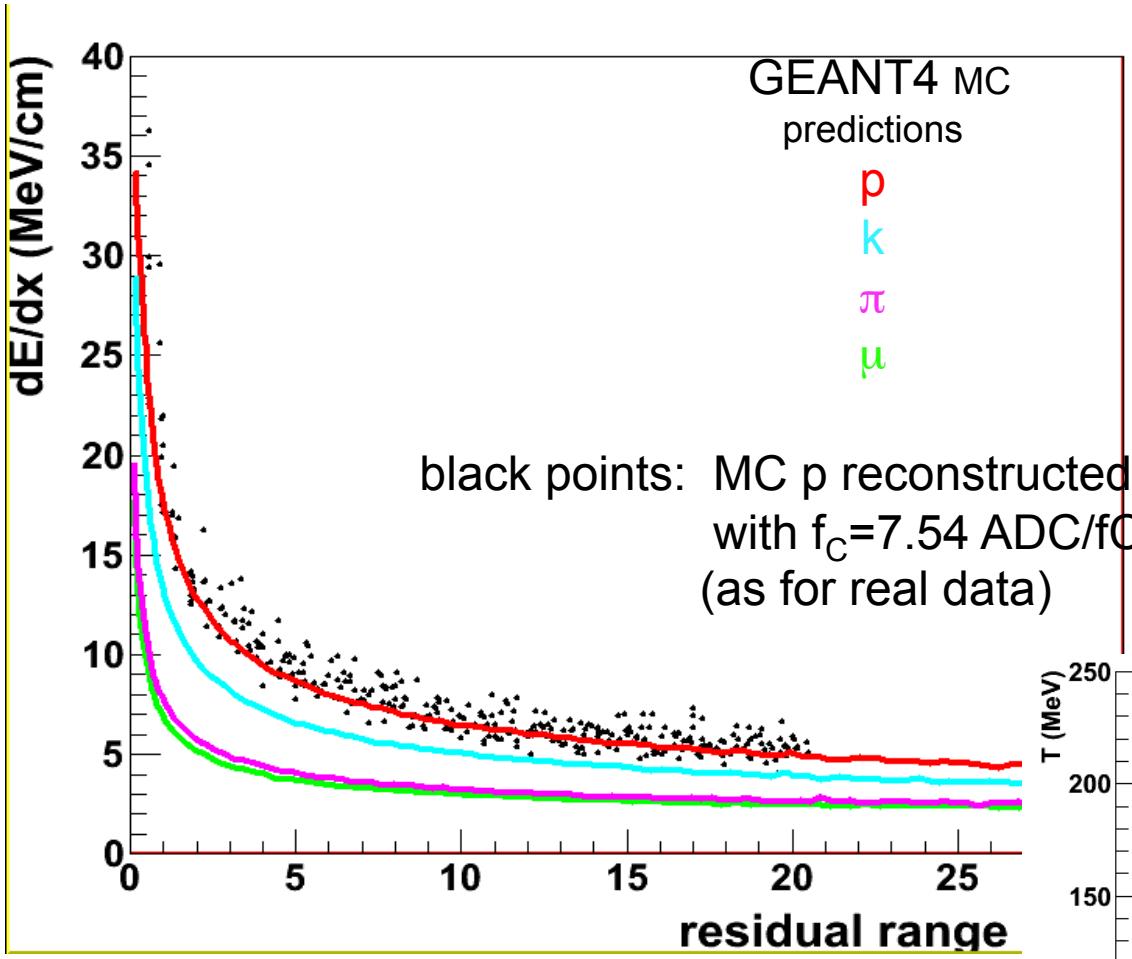


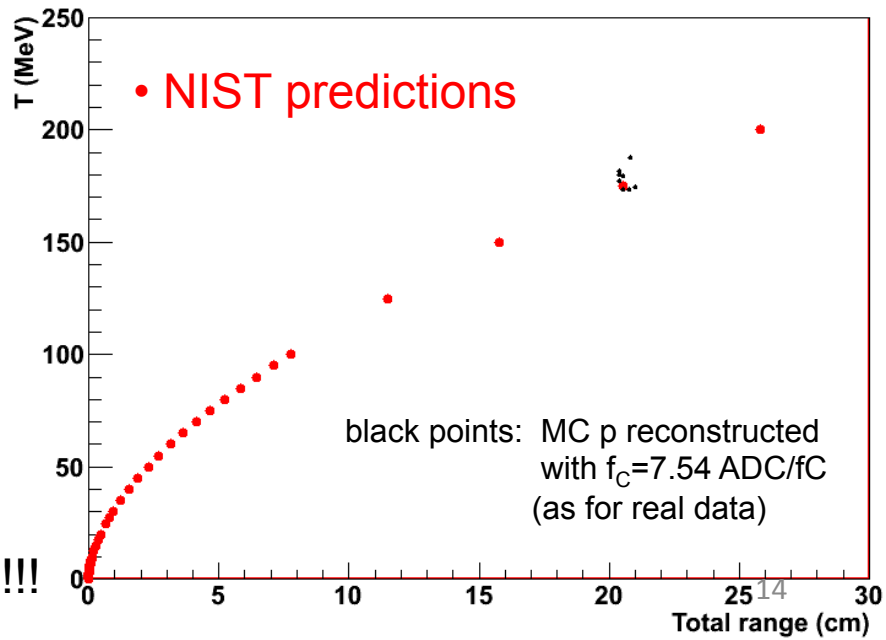
I Coll. wire ~ 35 ADC



Last Coll. wire ~ 105 ADC

Proton reconstruction –**after change**:

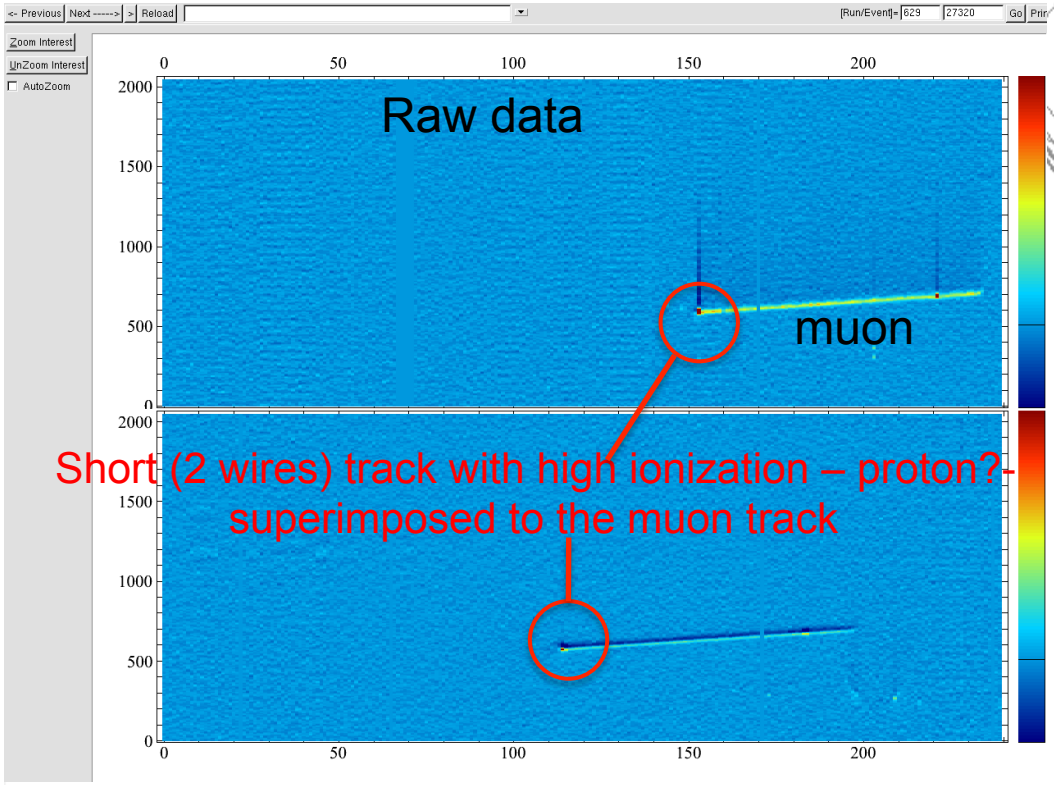


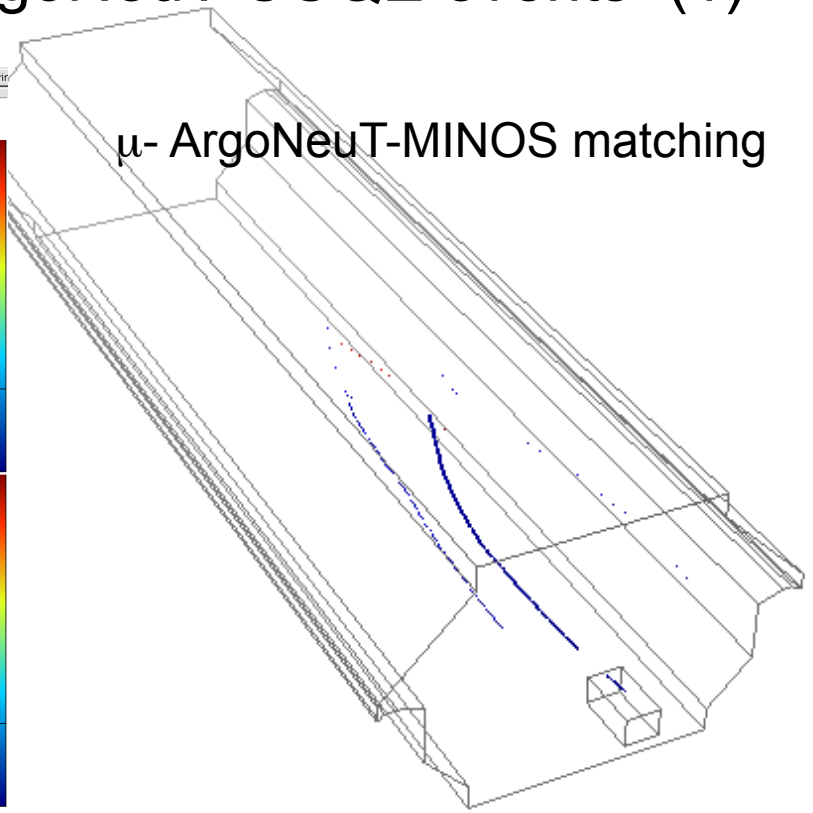


First and last hits are not included in this plot (because the actual extension of the track within the wire pitch is unknown)

Good agreement with GEANT-NIST prediction!!!!

Complete reconstruction of ArgoNeuT CCQE events (1)



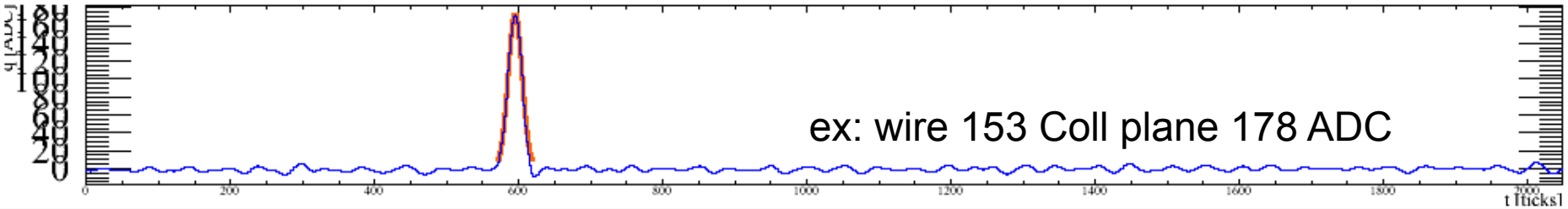



```
Run = 629 Event = 27320 #T962 Tracks = 1 #MINOS Tracks = 4
T962 Track ID    0 #SpacePoints =    80 #Clusters =   2 Theta =  0.108 Phi = -0.399
StartCosines : (  0.100 -0.042  0.994 )  EndCosines : (  0.100 -0.042  0.994 )

1 Matchable T962 tracks.
 MINOS TrkIndex  0  : Q =  -1 TrkVtx = (  2.046  -0.136   0.885 ) StartCosines = ( -0.056  -0.055   0.997 ) E =  7.45 Erange =  5.25 Mom =    6.94 Chi2 =   88.18
 MINOS TrkIndex  1  : Q =  -1 TrkVtx = (  1.440  -0.055   0.054 ) StartCosines = (  0.075   0.001   0.997 ) E =  4.58 Erange =  3.39 Mom =    3.81 Chi2 =   66.94
 MINOS TrkIndex  2  : Q =  -1 TrkVtx = ( -0.304   0.290   0.054 ) StartCosines = ( -0.041  -0.090   0.995 ) E =  1.02 Erange =  4.31 Mom =    0.00 Chi2 =    0.00
 MINOS TrkIndex  3  : Q =   1 TrkVtx = (  1.518   0.712   6.766 ) StartCosines = ( -0.661  -0.720   0.209 ) E =  4.05 Erange =  1.84 Mom =   17.67 Chi2 =    0.33
0 1 2.93 3.81
Run 629 Event 27320 Match! T962 Track #0 and MINOS Track #1.00
-* ArgoNeuT track #0, escaping
  |-*                    Track Length=38.09 cm
    |-* Collection View Calorimetric Reco
      |-* Hits=80
      |-* <dE/dx>=2.30 MeV/cm
      |-* Kinetic Energy deposited in LAr=87.52 MeV
```

Short track

Manual reconstruction of the short track from the signals on Coll and Ind
(subtracting the contribution of the muon, 30 ADC on average)



Coll: 2 hits, 1 with very high deposited charge, the second with very small
(1% of the first)

Reconstruction: track pitch length=0.47 cm, track length=0.47 cm (or slightly more)

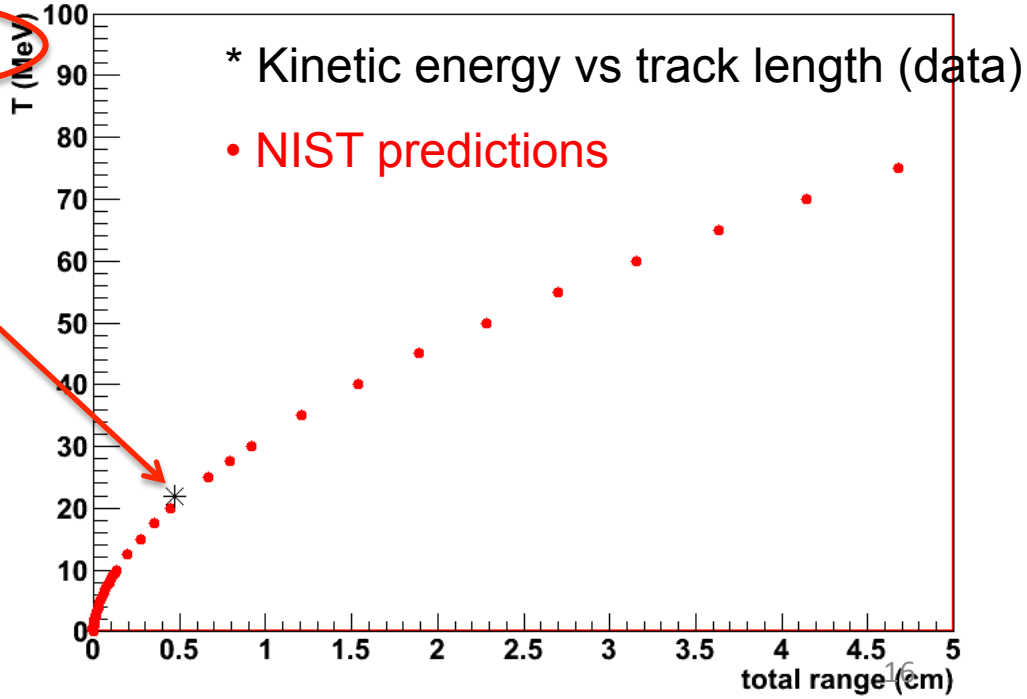
|-* <dE/dx>=23.2626 MeV/cm

|-* Ekin=21.9227 MeV

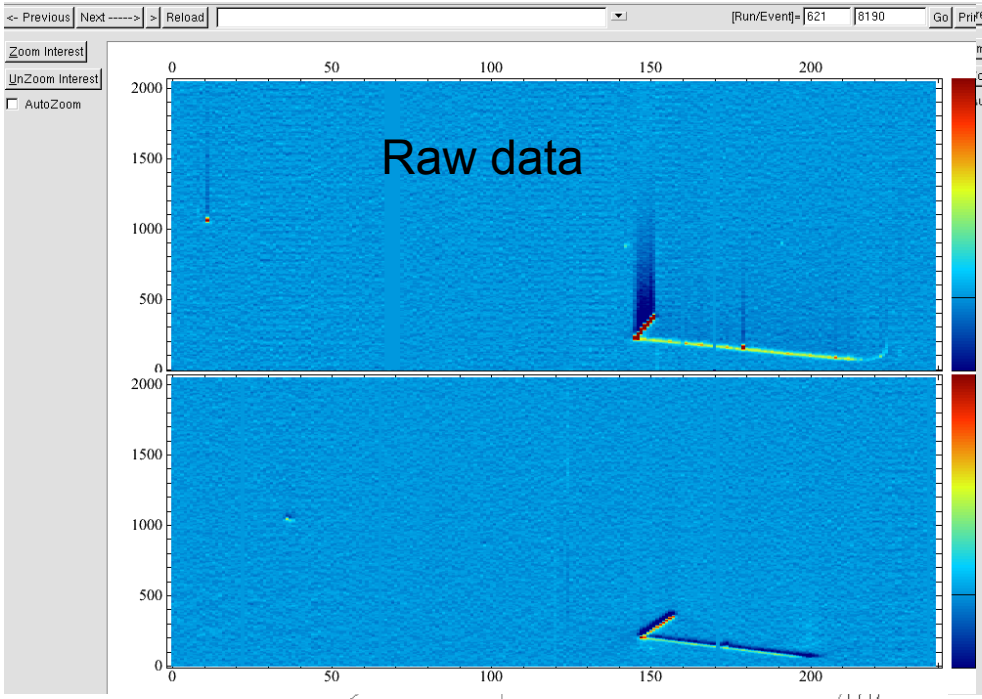
The short track behaves like proton

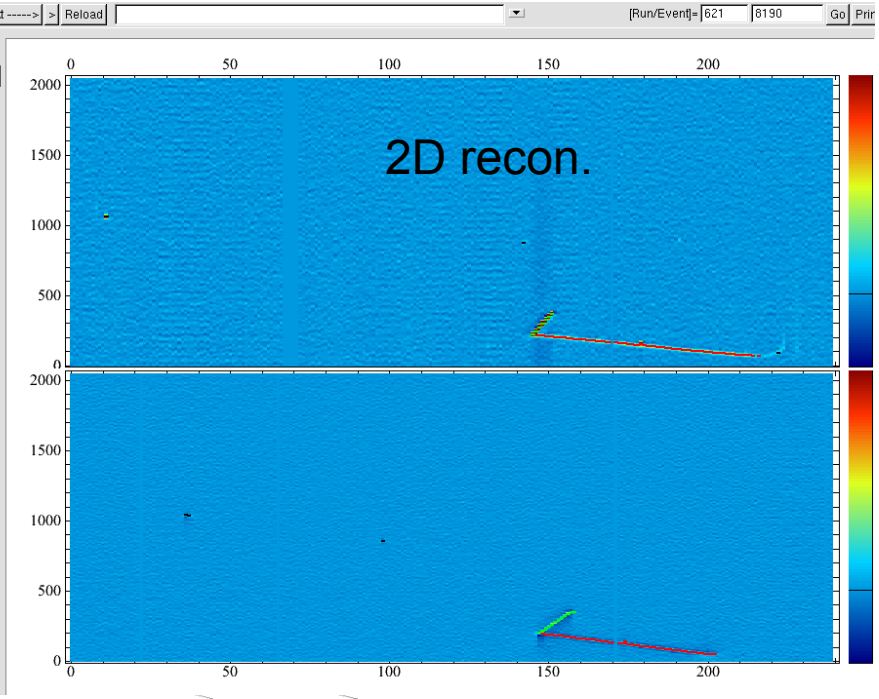
The event is (CCQE) 1p – 1 μ^-

ν energy can be reconstructed!

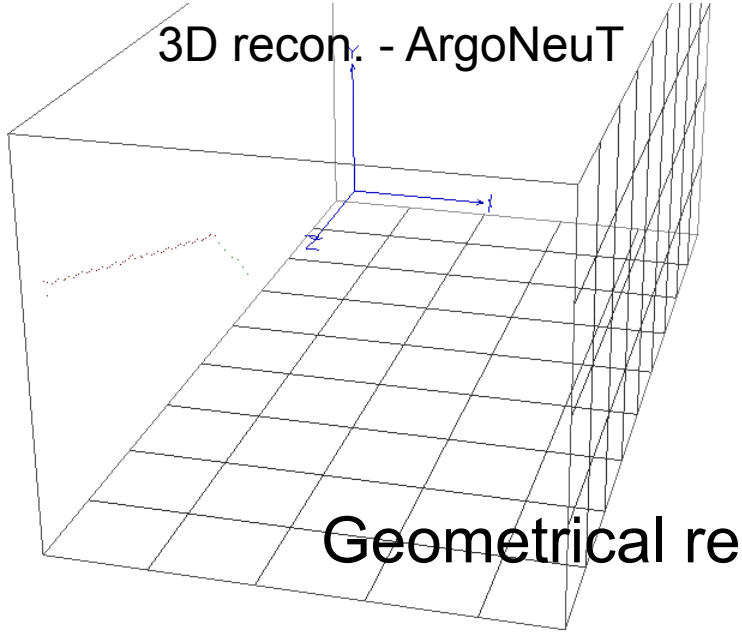


Complete reconstruction of ArgoNeuT CCQE events (2)

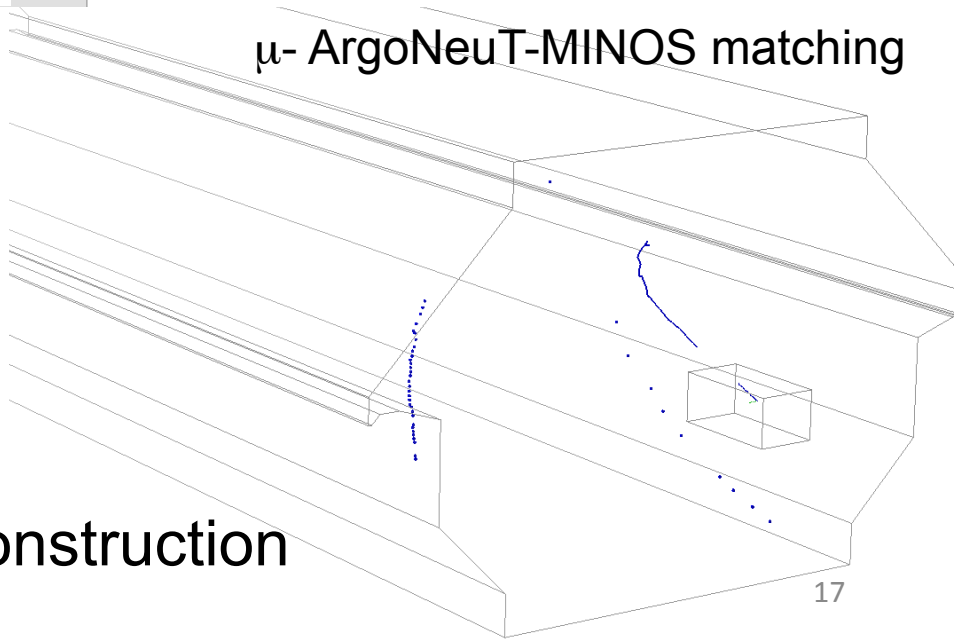




3D recon. - ArgoNeuT



μ- ArgoNeuT-MINOS matching



Geometrical reconstruction

Run = 621 Event = 8190 #T962 Tracks = 2 #MINOS Tracks = 3

T962 Track ID 0 #SpacePoints = 56 #Clusters = 2 Theta = 0.272 Phi = 2.233
StartCosines : (-0.165 0.212 0.963) EndCosines : (-0.165 0.212 0.963)

T962 Track ID 1 #SpacePoints = 7 #Clusters = 2 Theta = 0.931 Phi = -0.389
StartCosines : (0.742 -0.304 0.597) EndCosines : (0.742 -0.304 0.597)

1 Matchable T962 tracks.
MINOS TrkIndex 0 : Q = -1 TrkVtx = (2.337 -1.273 2.133) StartCosines = (-0.503 0.154 0.850) E = 1.84 Erange = 1.74 Mom = 1.87 Chi2 = 11.30
MINOS TrkIndex 1 : Q = -1 TrkVtx = (1.061 -0.010 0.054) StartCosines = (-0.162 0.224 0.961) E = 2.02 Erange = 1.45 Mom = 1.35 Chi2 = 12.65
MINOS TrkIndex 2 : Q = -1 TrkVtx = (0.239 -1.601 0.054) StartCosines = (-0.160 0.141 0.977) E = 0.55 Erange = 2.38 Mom = 2.56 Chi2 = 0.58
0 1 0.11 1.35
Run 621 Event 8190 Match! T962 Track #0 and MINOS Track #1.00

|-* ArgoNeuT track #0, escaping
|-* Track Length=33.15 cm
  |-* Collection View Calorimetric Reco
    |-* Hits=69
    |-* <dE/dx>=2.03 MeV/cm
    |-* Kinetic Energy deposited in LAr=59.66 MeV

|-* ArgoNeuT track #1, contained
|-* Track Length=6.54 cm
  |-* Collection View Calorimetric Reco
    |-* Hits=7
    |-* <dE/dx>=7.48 MeV/cm
    |-* Kinetic Energy deposited in LAr=57.37 MeV
    |-* <dE/dx>_5cm 8.26 MeV/cm

Contained track:
dE/dx vs. range not well matching proton expectations…
Not straight-line track!
Better reconstruction of track pitch length (hit by hit) needed

Calorimetric reconstruction

Summary

• The **missed density** in the recombination formula had relevant impact on MC simulated events!

•After the change: MC and real RAW data agree!!!

•Calorimetric reconstruction works properly both for real and MC ArgoNeuT data (for straight-line like tracks)

To be done:

- Calorimetry code and electronic calibration factor f_{cal}=7.54 ADC/fC for ArgoNeuT to be committed.

- Track pitch length calculated Hit-by-Hit;

-Test on MC neutrino events (ex. CCQE events - Kinga);

- Calculate threshold for proton reconstruction (OP-Kinga);

- Calorimetry code “experiment independent”. Test of calorimetric reconstruction of MicroBooNE MC events.

Backup

REAL DATA: Calorimetry summary

- The calorimetric reconstruction seems to work properly (if the tracking is well done). A better calorimetric reconstruction for non straight tracks can be implemented.

- Complete kinematic reconstruction of some neutrino events

- Particle ID for contained track.

- Mitch is setting up a tool to produce, together with the event display, the plot of dE/dx vs range for any contained track reconstructed

- Some ideas to implement a fast Particle ID procedure based on <dE/dx> in the last few cm of track before stopping

GEANT	μ	π	k	p	
$\langle dE/dx \rangle_{(0\text{-}30)\ cm}$	3.23	3.51	5.48	6.97	MeV/cm
$\langle dE/dx \rangle_{(0\text{-}5)\ cm}$	4.71	5.21	8.52	11.08	MeV/cm
$\langle dE/dx \rangle_{(0\text{-}2)\ cm}$	6.11	6.79	11.27	14.67	MeV/cm

- To be done: automatic Particle ID using a likelihood test